METHOD AND APPARATUS THAT ADAPTS CODING SCHEMES TO DATA RESOURCE LIMITS OF A MOBILE STATION COUPLED TO A PERIPHERAL DEVICE

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Field of the Invention

This invention is generally in the field of radio communication systems and more specifically in the field of packet radio communication system protocols.

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Background

In wireless networks employing General Packet Radio Service (GPRS), a coding scheme for data message transmissions is selected by rules
15   embedded in a fixed network and in a mobile station that are designed to result in the highest data throughput with the fewest possible retransmissions. GPRS is an extension of circuit-switched networks and data transmission services that uses packet radio transmissions to carry data messages using protocols such as Internet Protocol (IP) or X.25 information from mobiles to the network and
20   visa versa, in data blocks, or packets. GPRS is an extension to the circuit-switched Global System for Mobile communications (GSM), having four different coding schemes with effective data rates of 9.05, 13.4, 15.6 and 21.4 kilobits per second (code rates 1/2, 2/3, 3/4 and 1) when using one of the eight time slots available within a TDMA frame.
25   Some GPRS-enabled fixed networks can transmit data to a mobile station, such as a cell phone, an Internet-enabled mobile phone or a personal digital assistant, using a selected one of the four coding schemes. However, the mobile unit may have resource limitations that prevent it from accepting data at some of the higher coding schemes, such as an effective data rate that
30   is less than the maximum data rate that the mobile unit supports. Such a resource limitation arises when the mobile unit is coupled to a peripheral device using an effective downlink data transfer rate that is less than the maximum downlink radio channel data rate that the mobile unit can support. For example a mobile unit may act as a radio frequency modem for a personal computer

(the peripheral, for the purposes of this document) that is coupled to the mobile unit by a serial link that has an effective data rate less than the effective data rate of the RF downlink. Another inherent resource limitation is a finite depth of a buffer memory of the mobile unit used to buffer data being sent to the

5 peripheral device through the mobile unit. The fixed network can send data to the mobile station at a data rate greater than the effective downlink data rate determined by the link between the mobile unit and the peripheral, and the mobile unit can accept and acknowledge that data, until the buffer is full. At that time, the mobile unit has to being rejecting some of the downlink data

10 packets. With the move toward third-generation network standards, there are even more possible problems of these types with high-performance networks that use a wider variety of coding schemes.

Current GPRS fixed networks typically use dynamic link adaptation methods that monitor the quality of packet transfers and select one of the four

15 presently defined channel coding schemes (also referred to herein simply as "coding schemes") based on changing radio conditions. As technologies and protocols emerge and evolve for wireless data transmissions, additional coding schemes will become available. For example, GSM networks incorporating Enhanced Data for Global Evolution (EDGE) with packet-switched

20 enhancements for GPRS (also called Enhanced General Packet Radio Service) have nine additional coding schemes for increased performance. Other wireless network technologies such as GSM/EDGE Radio Access Network (GERAN) and Universal Mobile Telecommunications System (UMTS) provide enhanced coding schemes, requiring network algorithms that can

25 determine the coding scheme adaptability of the mobile station and direct coding scheme commands to the mobile station based on the adaptability. When the protocol or implementation of the radio communication system does not allow the reporting of the above mentioned resource limitations of mobile stations, downlink coding scheme determination methods in current use result

30 in sub-optimal data throughput due to re-transmissions that occur when the effective downlink data rate of the selected coding scheme exceeds the effective data transfer rate between the mobile unit and a peripheral device.

Brief Description of the Drawings

The present invention is illustrated by way of example and not limitation in the accompanying figures, in which like references indicate similar elements, and in which:

FIG. 1 is a schematic diagram of one embodiment of a system for determining coding scheme adaptation capability of a mobile station, in accordance with some embodiments of the present invention;

FIG. 2 is a block diagram of one embodiment of a system for determining coding scheme adaptation capability of a mobile station, in accordance with some embodiments of the present invention;

FIGS. 3-6 are illustrations of four coding schemes used for GPRS, in accordance with some embodiments of the present invention;

FIG. 7 is a time plot that shows uplink (TCP) acknowledgements when two coding schemes are used in a GPRS system, in accordance with some embodiments of the present invention;

FIG. 8 is a flow chart that shows a method of adapting coding schemes used on a downlink channel of a wireless packet data communication system, in accordance with some embodiments of the present invention;

FIG. 9 is a flow chart shows one method of monitoring whether the data transfer rate of the peripheral device is exceeded, in accordance with some embodiments of the present invention;

FIGS. 10 and 11 are flow charts that show details of the steps described with reference to FIG. 9, in accordance with some embodiments of the present invention;

FIG. 12 is a timing diagram that shows one example of the use of a binary search technique described with reference to FIG. 11;

FIG. 13 is a flow chart that shows more detail of a step of determining a buffer depth of a buffer memory of the mobile, in accordance with some embodiments of the present invention;

FIG. 14 is a time plot that shows data packets as an initial data message having a long set of data is being sent to a mobile station, in accordance with some embodiments of the present invention; and

FIG. 15 is a time plot that shows data packets of another data message having a long set of data, in accordance with some embodiments of the present invention.

Should figure 16 have an entry here?

5   Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

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Detailed Description of the Drawings

The present invention provides a method and apparatus that adapt coding schemes to data resource limits of a mobile station coupled to a

15   peripheral device, thereby maximizing downlink data throughput to mobile stations connected to a radio communication network that have a data transfer rate between the mobile station and the peripheral that is lower than the data rate of the highest coding scheme that is supported by the mobile station.

Before describing in detail the particular method and apparatus in

20   accordance with the present invention, it should be observed that the present invention resides primarily in combinations of method steps and apparatus components related to base station controllers for radio communication systems. Accordingly, the apparatus components and method steps have been represented where appropriate by conventional symbols in the drawings,

25   showing only those specific details that are pertinent to understanding the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

FIG. 1 shows a block diagram of one embodiment of a communication

30   system 100, in accordance with some embodiments of the present invention. The communication system 100 includes one or more public-switched telephone networks (PSTN) 110, an Internet 120, one or more mobile switching centers (MSC) 130, one or more general packet radio service support nodes (GSN) 140, one or more base site controller and packet controller units

(BSC/PCU) **150**, one or more radio tower or base transceiver stations (BTS) **160**, and one or more wireless mobile stations (MS) **180** such as a Internet-enabled cellular phone, a personal digital assistant or a laptop computer with wireless networking capabilities. Some of the wireless mobile stations **180** may

5   be coupled to a peripheral **185** by a link **186**, which is illustrated in **FIG. 1** as a wired link, but could alternatively be a wireless link.

An exemplary network technology that may be used for network operations is Global System for Mobile (GSM) communications, a digital cellular standard used throughout the world. GSM data services include circuit-

10   switched voice services, circuit-switched data, short message services (SMS), 2.5G and third-generation (3G) technologies that expand data-packet technologies and new multimedia types of wireless service. GSM uses three major frequency bands, including blocks of radio spectrum within the 900-, 1800-, and 1900-MHz bands. The 900- and 1800- MHz bands are the principal

15   bands used in Europe and Asia, and the 1900-MHz band is used in North America.

With wireless networks employing General Packet Radio Service (GPRS), a mobile station is commanded to transmit data blocks at the optimal coding scheme that the network determines will result in the highest data

20   throughput with the fewest possible retransmissions. For example, GPRS may offer transmissions via a GSM network within a range of 9.6 kilobits to 115 kilobits and allow users to make telephone calls and transmit data at the same time, the latter using an IP data transmission protocol.

Another embodiment of the wireless network may include Enhanced

25   Data for Global Evolution (EDGE), which is moving toward wideband code division multiple access (WCDMA). EDGE may be used as a packet-switched enhancement for general packet radio service (GPRS), known as enhanced GPRS or EGPRS, and as a circuit-switched data enhancement called enhanced circuit-switched data (ECSD).

30   Public-switched telephone network (PSTN) **110** is a land-based telephone network. PSTN **110** may comprise one or more switched lines over one or a combination of wire, fiber, or wireless links. PSTN **110** is typically connected to Internet **120** and MSC **130**.

Internet **120** is a public data communication network, which may comprise one or more electronic, optical or wireless communication paths with associated hardware and software to connect PSTN **110** with one or more wireless data devices **180**.

5   Mobile switching center **130** may receive signals from and send signals to wireless data device **180** via a general packet radio service support node (GSN) **140**, base site controller and packet controller units (BSC/PCU) **150**, and BTS **160**. MSC **130** may contain suitable hardware and software for ensuring that transmissions between wireless data device **180** and BTS **160**

10   are accurate and reliable. Accurate and reliable transmission of data packets (blocks) may require that certain data packets be retransmitted, or encoded in a manner such that the data packets are decoded at the receiver without requiring an additional transmission of the data packets. MSC **130** may communicate with PSTN **110**.

15   Mobile switching center **130** may be connected directly to Internet **120** via GSN **140** without requiring PSTN **110** as an intermediary. GSN **140** works with general packet radio service (GPRS), a packet-mode technique to transfer high-speed and low-speed data and to signal in an efficient manner over GSM radio networks. GPRS may employ GSN **140** to keep track of the location of

20   wireless data device **180** and to perform security functions and access control. GSN **140**, which is at the same hierarchical level as MSC **130**, may be connected to the system of BTS **160** with frame relay. GSN **140** provides interworking with external packet-switched networks such as Internet **120**, and is connected with GSN **140** via the IP-based GPRS backbone network. GSN

25   **140** can help MSC **130** with more efficient coordination of GPRS and non-GPRS services and functionality.

Base site controller and packet controller units (BSC/PCU) **150** may be connected to MSC **130**, GSN **140** and BTS **160**. The BSC/PCU 150 helps control BTS **160** in call set-up functions, coding schemes to use and use of

30   radio channels, and various maintenance tasks.

Base transceiver station (BTS) **160** contains suitable electronic equipment for transmitting and receiving radio frequency signals. BTS **160** may transmit and receive radio signals and more particularly, digitally encoded signals from wireless data device **180**. Communications between BTS **160** and

wireless data device **180** includes the transmission of data packets, which may be digitally encoded. The data packets may be intended for the peripheral **185** coupled to a wireless data device **180**.

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The data packets may be digitally encoded using a coding scheme (codes). The term scheme and code may be used interchangeably as appreciated by those skilled in the art. These schemes may be used in a variety of combinations with one or more received data packets. The transmission of data packets may use one or more modulation schemes, such as 16-QAM (quadrature amplitude modulation) or 8-PSK (phase shift keying). The modulation schemes and encoding schemes may be adaptively chosen based on factors such as requisite bit error rates (BER) or channel quality attributes. In accordance with the present invention, coding schemes are characterized in an ordinal relationship to each other, so that there are higher and lower coding schemes, with the higher coding schemes generally providing higher effective data throughput (i.e., the data rate not including error protection bits), and correspondingly requiring better environmental conditions to achieve sufficiently error free effective data throughput. Conversely, lower coding schemes generally employ either more redundant information or use slower modulation techniques to achieve effective data throughput that is similarly error free. Also, changing the coding scheme from a lower coding scheme to a higher coding scheme is referred to herein as raising the coding scheme, and conversely, a coding scheme can be lowered to a lower coding scheme. A successful transmission of multiple data packets comprising a data message may involve at least one additional transmission attempt (retransmission) of specific data packets whose contents were unsuccessfully decoded at the receiver. The retransmission may comprise a repeated transmission of the data packet that was corrupted in the channel. The retransmission may be sent at a lower coding scheme to improve the reliability of the data. The retransmission may also be sent using the same coding scheme, such as a repeated transmission. The retransmission may be sent at a higher coding scheme for faster data throughput. The coding scheme selection may be determined, for example, with feedback from wireless data device **180**, by a data scheme selected by the packet control unit (PCU) portion of the BSC/PCU **150** and

communicated to the BTS **160**. A detailed description of some of the rules for selecting a coding scheme is given below with reference to FIGS. 7-9.

Wireless data device **180**, which may be a cellular phone, a laptop computer, a wireless modem coupled to a laptop computer or other peripheral device, a PDA or other wireless device, is equipped with suitable hardware and software for receiving and transmitting digital transmissions. Wireless data device **180** typically transmits or receives data in a prescribed band of frequencies nominally at 900 MHz, 1900 MHz, or any other suitable band of frequencies prescribed for wireless communication. Wireless data device **180** may be carried by a human user, installed on mobile equipment, used in a fixed location such as on a desk or used in any other application where wireless communication services are desired.

FIG. 2 is a block diagram of one embodiment of a communication system **200**, in accordance with the present invention. Components of communication system **200** include a public-switched telephone network (PSTN) **210**, a mobile switching center (MSC) **230**, base station subsystem (BSS) **250**, and a packet radio network **290**.

Public switch telephone network (PSTN) **210**, a land-based telephone network, is coupled to the MSC **230**. The packet radio network **290** comprises an Internet-protocol network **220** is coupled to, one or more GPRS support nodes (GSN) **240**, which are coupled to one or more packet controller units (PCU) **254**. One or more wireless data devices **280** form a portion of the packet radio network **290**.

GPRS support nodes (GSN) **240**, as payload-carrying and control devices, help the network to switch packet data, routing packets to and from the geographical area of packet radio-specific network **290** and interfacing with Internet-protocol network **220**. GSN **240** may be physically separate from the circuit-switched part of a cellular system core network, as shown in FIG.2, where it is coupled to the MSC 230, or may be integrated with the MSC 230. GSN **240** contains GPRS backbone network protocol (IP) routing functionality, and can be interconnected with IP routers.

Packet Controller Unit (PCU) **254** serves as an interface between BSS **250** and packet radio-specific network **290**, performing radio functions and general packet radio service (GPRS) network functions. In addition to PCU

254, base site (or base station) controller (BSC) **252** and base transceiver station (BTS) **260** are components of BSS **250**. BSC **252** controls radio signals of multiple cell sites, thus reducing the load on MSC **230**. BSC **252** also performs radio signal management functions for BTS **260**, managing functions

5 such as frequency assignment and handoff. BTS **260**, which may be equipped with antenna and radio equipment, is the central radio transmitter/receiver that maintains communications with mobile station (MS) **270** within its cell site or given range.

Mobile station **270** consists of mobile equipment such as a cellular

10 phone and is used to communicate with the GSM network. Mobile station **270** may be coupled to or physically integrated with the data device (DD) **280**, which may be a device such as a mobile personal digital assistant (PDA) or a laptop computer. Coupling between the MS **270** and the data device **280** can be, for instance, a wired link such as an RS-232 link, or could be by a wireless

15 local area network link such as an infrared link, either of which may have a 56Kbps limitation, or a link such as those specified in IEEE 802.11. Such links could be used whether or not the MS **270** and DD **280** are physically integrated, but are more likely to be used only when the MS **270** and DD **280** are not physically integrated. Mobile station **270** couples to base transceiver

20 station **260** via air interface **262**, which is a preferably standard signaling system of a standard wireless network technology, preferably conforming to one of the GSM standards. When the MS **270** and DD **280** are physically integrated, then the functions of both may be provided by one processor, or the functions may be provided by two processors coupled by links that can couple

25 data at speeds substantially higher than those that are possible using the air interface **262**. For the purposes of this document, whenever the MS **270** and DD **280** are coupled by a link that has a lower data rate than the highest data rate of the air interface, then DD **280** is referred to hereinafter as a peripheral device to the MS **270**, whether or not the DD **280** is physically integrated with

30 the MS **270**. The average data rate that can be achieved between the MS **270** and the peripheral device **280** is hereinafter termed the data transfer rate.

The portion of the communication network comprising the MSC **230**, the GSN **240** and the BSS **250** may be called the fixed network.

Other network topologies besides the network architecture described

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above are possible without departing from the essential characteristics of the present invention. Additional components to separate various functions of a piece of equipment or module may be included with departing from the nature of the present invention.

5   As previously mentioned, the PCU **254** manages, allocates, and schedules the packet data resources necessary to allow uplink and downlink packet data transmission between the BTS **260** and the MS **270** with its associated peripheral device **280**. Specifically, a packet resource manager (not shown) within the PCU **254** receives data, determines how to best "package"

10   the data, and then instructs (via control instructions) the BTS **260** to package the data accordingly. Once received by the MS **270** from the BTS **260**, the data packages are "unpackaged" and reassembled, thereby completing the transmission of the data to the MS **270**, which then may transfer the unpackaged data to the peripheral device **280**, depending on the nature of the

15   contents of the unpackaged data

For example, layer 2 user data bits received by the PCU **254** from the IP internet **220** via the GSN **240** (resulting from a particular software application) are in the form of Logic Link Control (LLCs) frames. Upon receipt, the PCU **254** splits each of the LLCs into segments of bits and inserts

20   additional bits (e.g., polling bits, data encoding instructions, etc.). The resulting blocks of bits, herein referred to as "segmented blocks," are forwarded to the BTS **260** for transmission as a downlink data message. Based on the data encoding instructions embedded in the segmented blocks by the PCU **254**, the segmented blocks are encoded, or modulated, by the BTS **260** using the

25   GPRS coding schemes, and the downlink data message is transmitted to the MS **270** as GPRS radio blocks. Similarly, a data message can be generated by the mobile data device **280** and transmitted from the MS **270** using the GPRS coding schemes. Current GPRS coding schemes selectable by the PCU **254** include Coding Scheme 1 (CS-1), CS-2, CS-3, or CS-4 (see, FIGS. 3-6) and

30   Modulated Coding Scheme 1 (MCS-1), MCS-2, MCS-3, MCS-4, MCS-5, MCS-6, MCS-7, MCS-8, and MCS-9.

The particular GPRS coding scheme selected by the PCU **254** and MS **270** is based on whether the data is control data requiring maximum protection for transmitted bits, or maximum data integrity, requiring CS-1 coding, or

whether the data is user data. If the data is user data, varying coding schemes (e.g., CS-1 through CS-4) are selected by the PCU **254**, generally based on channel quality factors and knowledge of the coding scheme capabilities of the MS **270**, as described in more detail with reference to FIGS. 7 and 8 below.

5   The BTS **260** and the MS **270** encode the data into the GPRS radio blocks suitable for transmission over the Packet Data Traffic Channel between the BTS **260** and the MS **270**. For ease of discussion, the GPRS radio blocks carrying encoded data may be referred to herein as "GPRS data blocks".

       FIG. 3 is an illustration of coding scheme 1 (CS-1) **300** for maintaining
10   maximum data integrity of GPRS radio blocks in a GPRS packet data transmission channel (PDTCH), in accordance with the preferred and alternative embodiments of the present invention. Referring to **FIG. 3**, for the CS-1 **300**, 181 Layer 2 bits resulting from applications (e.g., email, web browser, paging, etc.) as well additional information bits inserted by the PCU
15   **254** are forwarded to the BTS **260** as a portion of a downlink data message (or possibly as a complete, short data message). (Of course, as is known, thousands of bits of layer 2 data may be received by the PCU **254** as a data message from a particular application). Based at least partially on the number of bits received and the information bits inserted by the PCU **254**, a
20   predetermined number of uplink state flag (USF) bits **303** are added to the 181 Layer 2 bits **302** by the BTS **260**. The USF bits **303** are configured to notify a particular MS **270** that it has uplink transmission rights. Similarly, parity bits **304** and tail bits **306** are added to the 181 Layer 2 bits for error correction, herein referred to as a "block check sequence" (BCS). The addition of the USF bits
25   **303**, the parity bits **304** and the tail bits **306** to the Layer 2 bits **302** results in 228 bits to be encoded. To maximize data integrity during transmission, each of the 228 bits of data is copied, resulting in 228 original bits and 228 copied bits for a total of 456 bits (i.e., a 1/2 code rate) to be transmitted from the BTS **260** to the MS **270**. As is known in the art, each group of 456 bits may be referred
30   to a one GPRS data block. The 456 bits are distributed among four "bursts" containing approximately 114 bits/burst (i.e., one TDMA frame) shown in **FIG. 3** as bursts **308, 309, 310, 311**. Thus, two copies of each the original 181 Layer 2 bits **302** are transmitted from the BTS **260**, thereby increasing the odds that each of the original 181 Layer 2 bits **302** are received by the MS **270**. Typically,

the four bursts **308-311** are transmitted with forty-four additional bursts **312** (representing eleven additional GPRS radio blocks), and four idle bursts (i.e., TDMA frames) in a "multiframe" configuration. As shown in FIGs. 3-6, a multiframe **320** is transmitted in approximately 240 milliseconds. Upon receipt of the multiframe(s) **320**, using well-known methods, bits inserted in the bursts by the BTS **260** at the direction of the PCU **254** are used by the MS **270** to decode and reconstruct the data is a form suitable for receipt by an end user.

Of course, as will be appreciated by those of ordinary skill in the art, the "cost" of using the CS-1 scheme is high in terms of bandwidth resources; less than one data message bit is recovered for every 2 bits transmitted. The GPRS PDTCH coding schemes CH-2, CH-3, and CH-4 are constructed to more efficiently utilize bandwidth resources, depending on the quality or robustness of the communication channel **124**. More particularly, CH-2 and CH-3 utilizes controlled bit reduction, herein referred to as "bit puncturing" to reduce the amount of copied data bits transmitted. Moreover, CH-4 adds only USF and parity bits to the original layer 2 bits prior to transmission to the MS **270**; no copied bits are transmitted.

For example, **FIG. 4** is an illustration of the coding scheme 2 (CS-2) **330** where approximately 1/3 of the copied bits are punctured. Referring to **FIG. 4**, for CS-2, 268 Layer 2 bits **332** are transmitted from the PCU **254** to the BTS **260**. Similar to CS-1 **300**, 6 USF bits **333**, 16 parity bits **334** and 4 tail bits **336** are added to the 268 Layer 2 bits **332**. The addition of the USF bits **333**, the parity bits **334** and the tail bits **336** to the Layer 2 bits **302** results in 294 bits to be encoded. Each of the 294 bits of data is copied resulting in 294 original bits and 294 copied bits for a total of 588 bits. Of the 588 bits, however, only 456 bits are transmitted (i.e., a 2/3 code rate) from the BTS **260** to the MS **270**. The remaining 132 are selectively discarded based on known statistics. Thus, the original 268 Layer 2 bits **332** and approximately 2/3 of the copied 268 layer 2 bits are transmitted from the BTS **260** to the MS **270**.

FIG. 5 is an illustration of the coding scheme 3 (CS-3) **340** where approximately 2/3 of the copied bits are punctured. Referring to **FIG. 5**, for CS-3, 312 Layer 2 bits **332** are transmitted from the PCU **254** to the BTS **260**. Like CS-2 **330**, 6 USF bits **343**, 16 parity bits **344** and 4 tail bits **346** are added to the 312 Layer 2 bits **342**. The addition of the USF bits **333**, the parity bits **334**

and the tail bits **336** to the Layer 2 bits **302** results in 338 bits to be encoded. Each of the 338 bits of data is copied resulting in 338 original bits and 338 copied bits for a total of 676 bits. Of the 676 bits, however, only 456 bits are transmitted (i.e., a 3/4 code rate) from the BTS **260** to the MS **270**. The

5 remaining 220 bits are selectively discarded based on known statistics. Thus, the original 312 Layer 2 bits **342** and approximately 1/3 of the copied 312 layer 2 bits are transmitted from the BTS **260** to the MS **270**.

FIG. **6** is an illustration of a coding scheme 4 (CS-4) **350** where no copied bits are generated and no bits are punctured. Referring to **FIG. 6**, for

10 CS-4, 428 Layer 2 bits **352** are transmitted from the PCU **254** to the BTS **260**. Unlike coding schemes CS-1, CS-2, and CS-3, only USF bits **353** and parity bits **354** are added to the Layer 2 bits. The addition of 12 USF bits **353** and 16 parity bits **354** to the 428 Layer 2 bits **352** results in exactly 456 bits. Thus, only the original 428 Layer 2 bits **352** are transmitted from the BTS **260** to the MS

15 **270**.

When the MS **270** transmits a data burst to the BTS **260** in an uplink data message using one of the coding schemes CS-1, CS-2, CS-3, or CS-4, the data message bits and error control bits are arranged similarly to those in downlink data message bursts. However, the control bits that are included in an

20 uplink burst have meanings different from those of the USF bits in a downlink burst and may be different in number than the USF bits of a downlink burst.

The CS-4 **350** provides the most efficient utilization of bandwidth resources and is therefore the coding scheme of choice when channel conditions of the communication channel **124** permits (i.e., optimum channel

25 conditions) and the equipment (BTS **260** and MS **270**) is capable of such encoding scheme. Conversely, the CS-1 **300** provides the most reliable scheme to ensure data integrity of the GPRS radio blocks received or transmitted by the MS-1 and is therefore the coding scheme of choice when the communication channel **124** is adversely affected or when transmission of a

30 control information message is required. The CS-2 **330** and the CS-3 **340** provide intermediate coding schemes.

As will be appreciated by those of ordinary skill in the art, coding schemes for GPRS PDTCH can be achieved using a number of coding

schemes, for example modulation and coding schemes, MCS-1 to MCS-9 suitable for use with enhanced GPRS.

GSM specifications include requirements that mobile stations **270** that are designed for use in GPRS systems be capable of receiving and transmitting the four defined coding schemes CS-1, CS-2, CS-3, and CS-4. Particularly in instances in which the MS **270** can operate using CS-3 or CS-4, the data device **280** may operate as a peripheral device – that is, the data transfer rate to the data device **280** may be slower than the downlink data rate from the base transmitter station (BTS) **260** to the MS **270**. In systems that use GPRS, there is no standard for conveying to the Base Station Subsystem **250** or packet radio network **290** the data transfer rate from the MS **270** to the DD **280**. As a result, the MS **270** may attempt to send a long set of data to the MS **270** that is intended for the DD **280** at a data rate that exceeds the data transfer rate. A consequence of such a transfer is that a buffer memory in the MS **270** that allows temporary storage of data being transferred from the MS **270** to the DD **280** can overflow, causing retransmissions by the BSS **250** that ultimately convey the data to the DD **280**, but cause the effective downlink data rate to degrade. This invention overcomes this problem. It will be appreciated that the inventive methods described herein also apply to packet data communication systems that have other sets of coding schemes, of which the EDGE system is one example, and for which at least some mobile stations do not respond to a command to switch to particular coding schemes.

Referring to **FIG. 7**, a time plot shows uplink (TCP) acknowledgements when two coding schemes are used in a GPRS system, in accordance with some embodiments of the present invention. When a coding scheme is used that has an effective bit rate lower than the data transfer rate between the mobile station **270** and a peripheral device **280**, and bit error rate of messages received by the MS **270** is low, acknowledgements transmitted by the MS **270** would typically look very regular, as shown by the acknowledgment tracking report **710**. An example of this type of situation would be an MS **270** having a serial interface with a maximum data rate of 57.6 kbps linking the MS **270** to the peripheral device **280**, while the data packet coding scheme used is CS-3, which has an effective data rate of approximately 53 kbps when all four bursts in each frame are dedicated to one MS **270** for the entire message. When a

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coding scheme is used that has an effective bit rate higher than the data transfer rate between the mobile station **270** and a peripheral device **280**, and bit error rate of messages received by the MS **270** is low, acknowledgements transmitted by the MS **270** would look very regular for while, but then packets
5   would begin to be dropped, as shown by the acknowledgment tracking report **705**. The dropping of the packets occurs when a buffer in the MS **270** overflows as a result of packets not being moved to the peripheral device **280** quickly enough. An example of this type of situation would be an MS **270** having a serial interface with a maximum data rate of 57.6 kbps linking the MS
10   **270** to the peripheral device **280**, while the data packet coding scheme used is CS-4, which has an effective data rate of 72 kbps.

Referring to **FIG. 8**, a flow chart shows a method **800** of adapting coding schemes used on a downlink channel of a wireless packet data communication system, in accordance with some embodiments of the present
15   invention. The coding schemes are adapted to achieve an optimal combination of coding schemes having an optimal data rate, according to data resource limits of a mobile station coupled to a peripheral device. The data resource limits of primary concern are the data transfer rate between the mobile station and the peripheral device, and the buffer depth of a memory that stores data in
20   the mobile station for transfer to the peripheral device when a currently received data packet cannot be transferred to the peripheral device because earlier packets are still being transferred to the peripheral device. The method **800** may be implemented entirely within the BSC **252** by one or more processors that execute programmed instructions, or it may be distributively
25   implemented in any combination of portions of the fixed network devices, which in this system example include the MSC **230**, the GSN **240**, BTS **260**, and the BSS **252**. In accordance with embodiments of the present invention, no changes are needed in the mobile station **270** or peripheral device **280** to implement the present invention. At step **805**, a data transfer to a mobile
30   station is started on the downlink of a radio communication system for the purpose of establishing an optimal combination of coding schemes. This may be done when the mobile station first becomes active in the radio communication system, or may be done when large amounts of data are queued up for the mobile station, or may be done when a certain amount of

data is queued up for the mobile station and an optimal data rate has not been tested for a fixed time period. Other strategies could be used to determine the optimal combination of coding schemes. At step **810**, an initial value of a current combination of coding schemes that will be used to transmit a set of
5 data is selected to be the highest coding scheme supported by the mobile station, used at a highest duty cycle. In the case of a GPRS system, the highest duty cycle is four bursts (also called time slots) per frame. In a situation in which the highest coding scheme is not known to the fixed network equipment, it may be appropriate to establish the highest coding scheme
10 supported by the mobile station before performing step **810**. In subsequent loops of the method, the current combination of coding schemes may include more than one coding scheme, each having a duty cycle. It will be appreciated when the current combination of coding schemes uses, for example, two coding schemes, each at duty cycle of two time slots per frame; a current data
15 rate that is between the effective data rates of each of the two coding schemes can be achieved.

A set of data is then transmitted on the downlink channel to the mobile station at step **815**, using the current combination of coding schemes, which provide a current data rate. Monitoring is then done, at step **820**, to determine
20 whether the data transfer rate of the peripheral device has been exceeded. The results of the monitoring are used at step **825** to determine whether a search criterion has been met, and when the search criterion is met, the optimal combination of coding schemes is established as the current combination of coding, at step **840**. When the search criterion is not met at step **825**, a new
25 coding scheme combination having a new data rate different from the current data rate is determined at step **830** for use in another trial (or loop of the method). The current coding scheme combination is set to the new coding scheme combination at step **835** and an additional set of data is transmitted to the mobile station at step **815** using the current coding scheme combination.
30 Thus the steps of transmitting **815**, monitoring **820**, establishing **830**, and setting **830** may be repeated until the search criterion has been met at step **825**

In another aspect of the present invention, a buffer depth of the mobile station may be determined at step **845** after the optimal coding scheme combination has been determined at step **840**. Optionally, as indicated by

dotted path **846**, a buffer depth determination is not used in the method. A timer is started at step **850** after the optimal coding scheme is determined at step **840** (and after the optional buffer depth determination step **845** if it is used). Until the timer times out at step **860**, data messages are transferred to the mobile station using the optimal coding scheme combination, and optionally using the buffer depth. This timer may be set for several seconds, to allow for changing resource conditions (e.g., allocated mobile buffer size and changing peripheral data transfer rates. This method **800** optimizes the transfer of data from the fixed network to the peripheral device.

Referring to **FIG. 9**, a flow chart shows one method of monitoring whether the data transfer rate of the peripheral device is exceeded at step **820**, in accordance with some embodiments of the present invention. At step **905**, a determination is made whether the downlink and uplink channels are sufficiently error free. This can be done, for instance, by inference from a recent coding scheme negotiation between the mobile station and the fixed network having resulted in a decision that a high coding scheme, such as CS-3 or CS-4 could be used. Such a decision may be one that is made only when the downlink and uplink channels are sufficiently error free. Another technique would be to use a low coding scheme that is unlikely to cause data transfer errors due to buffer overflow, and determine channel quality by a uniformity of acknowledgements. There are other techniques, such as measuring received signal strengths at the mobile station and base transmitter station. When the downlink and uplink channels are determined not to be sufficiently error free at step **905**, the method for optimizing the coding schemes may be abandoned at step **915**, or (not shown in **FIG. 9**) a low initial coding scheme combination may be used at step **810**. When the downlink and uplink channels are determined to be sufficiently error free at step **905**, a determination is made at step **910** as to whether intervals of acknowledgements transmitted from the mobile station on the uplink channel in response to the set of data meet uniformity criteria. Such uniformity may require, for instance, that every downlink data packet is acknowledged, or may allow some low number of missing acknowledgements. The results of the uniformity determination are provided as inputs to step **825**.

Referring to **FIG. 10**, a flow chart shows details of the steps **825** and **830** described with reference to **FIG. 9**, in accordance with some embodiments

of the present invention. At step **825**, a determination is made whether the data transfer rate of the peripheral has been exceeded or not, which is determined by whether the uniformity criteria are met or not at step **820**. When the data transfer rate is determined to have been exceeded at step **825**, a new coding

5   scheme combination is selected that has a lower data rate than the current coding scheme combination and the method continues as described with reference to **FIG. 8**. The lower data rate may be different than the data rate of the current coding scheme by an amount approximately equal to a fixed amount. In one embodiment, the new coding scheme combination has a data

10   rate that is one half of the current coding scheme combination. A duty cycle of the coding scheme combination may be chosen based on an amount and relative priority of data traffic queued for other mobile stations from the same fixed network entity. The entity could be, for example, a base transmitting station or a base station controller. For example, when there is little traffic for

15   other mobile stations, then the optimal code scheme combination could use two lower code schemes (e.g., CS-2, CS-3) with more average time slots per frame, which might be preferable when the error rates of the downlink and uplink channels are known to have degraded. When there is other equal or higher priority data traffic queued for other mobiles, then, for example, only CS-

20   3 could be used, but with fewer average number of time slots per frame. An optimal data scheme combination may use a varying number of time slots in frames to achieve a selected optimal (average) data rate. This varying duty cycle can achieve an accommodation of varying data traffic from other mobile stations by allowing the use of varying amounts of times slots for the other

25   mobile stations while at the same time the duty cycle of each code scheme used by the mobile station that is communicating using an optimized code scheme is changed to maintain an optimized data rate. Thus, the term combination of coding schemes means a dynamic combination of coding scheme levels and duty cycles that achieves a selected (average) data rate.

30   When the data transfer rate is determined not to have been exceeded by the current data rate at step **825**, then the search criterion has been met and the method continues at step **840** via path **826**

Referring to **FIG. 11**, a flow chart shows details of the steps **825** and **830** described with reference to **FIG. 9**, in accordance with some binary search

embodiments of the present invention. At step **1105**, a first test is whether the {monitoring whether the data transfer rate of the peripheral device has been exceeded} has a result that is changed from a previous such result. When there has been a change in the result, a determination is made at step **1110** as

5   to whether the absolute value of the difference of the current data rate and a most recent data rate is less than a precision limit. When the difference is less than the precision limit at step **1110**, then the search criterion are met and the method **800** continues at step **840** (**FIG. 8**) via path **826**. When the difference at step **1110** is not less than the precision limit, or when the result of the first

10 test at step **1105** is that no change has occurred, a new combination of coding schemes is determined at step **830** that has a data rate (an average data rate) that different than the current data rate by an amount that has an absolute value based on the current data rate and a most recent data rate, and a sign based on the result of the monitoring **1115**. For example, the absolute value of

15 the amount may be approximately one half of a difference of the current data rate and the most recent data rate (down to some lower limit), and the sign may correspond to whether the current data rate is greater than the data transfer rate.   In this instance an initial coding scheme combination may be set to the data highest code scheme and full duty cycle, while a second initial coding

20 scheme combination may be set to the lowest code scheme with the lowest duty cycle.

Referring to **FIG. 12**, a timing diagram shows one example of the use of the binary search technique described with reference to **FIG. 11**. In this example a mobile station coupled to a peripheral has a data transfer rate **1205**

25 shown by the dotted line. An initial coding scheme combination is used that consists of a highest coding scheme combination, e.g., CS-4 at a 100% duty cycle, having a high data rate **1210** that becomes the current data rate. When this coding scheme combination is tested between T1 and T2, the result is that the current data rate **1210** is greater than the data transfer rate **1205**. An

30 second initial coding scheme combination is then used that consist of a lowest coding scheme combination, e.g., CS-1 at a 25% duty cycle, having a low data rate **1215** that becomes the current data rate. The current combination of coding schemes is further as a result of steps **1105** and **1110**, which may be done by using two or more coding schemes and average duty cycles for each

coding scheme. The average duty cycle for each coding scheme combination may be achieved by changing the duty cycle for the coding scheme from frame to frame. The adjustments result in exemplary current data rates **1210**, **1215**, **1220**, **1225**, and **1230** shown in **FIG. 12**. The difference between data rate

5   **1230** and **1225** is less than the limit and a change has occurred in the determination as to whether the current data rate exceeds the data transfer rate, so the current data rate **1230** becomes the optimal data rate. This technique has been described to illustrate that a variety of search and determination techniques **825**, **830** may be successfully used in accordance

10   with the present invention.

Referring to **FIG. 13**, a flow chart shows more detail of the step **845** of determining a buffer depth of a buffer memory of the mobile station when the search criterion has been met at step **825**, in accordance with some embodiments of the present invention. A long set of data is transmitted on the

15   downlink channel to the mobile station at step **1305** using a fast combination of coding schemes that has a fast data rate that is supported by the mobile station and is greater than a data rate of the optimal combination of coding schemes. This fast combination of coding schemes in a GPRS system may be, for example, CS-4 at 100% duty cycle; but it should be a coding scheme that the

20   mobile station supports. (In some systems, not all mobile stations support all defined coding schemes. If a mobile station only supports coding scheme combinations [coding scheme levels and duty cycles] for which the fastest is deemed slower than any peripheral likely to be used, then the optimal coding scheme combination would be that fastest supported coding scheme

25   combination. At step **1310**, a duration from a start of the transmitting to a time at which the buffer depth of the mobile station has been exceeded is determined. The buffer depth (also called buffer capacity) is then estimated at step **1315**, using the duration and a difference of the fast data rate and the data rate of another combination of coding schemes that has been tested during the

30   method 800. One combination of coding schemes to use for the buffer capacity estimation may be the combination that had an effective coding rate closest to, but greater than, the optimal coding scheme combination. The use of this combination should provide an estimate of the buffer capacity that is less than or equal to the actual size. Another combination of coding schemes to

use for the estimation is the optimal combination of coding schemes. This value may yield a value greater than the actual buffer capacity, but may be satisfactory, particularly when a more accurate method of determining the optimal combination of coding schemes is used, such as that described with

5   reference to **FIG. 11**. Determining that the buffer capacity has been exceeded may comprise determining that intervals of acknowledgements transmitted from the mobile station on the uplink channel in response to the long set of data meet non-uniformity criteria, and may further comprise determining that the downlink and uplink channel are sufficiently free from errors due to path losses.

10 Note that steps **1305** and **1310** may be performed earlier in the method 800, such as between steps

Referring to **FIG. 14**, a time plot shows data packets as an initial data message having a long set of data is being sent to a mobile station, in accordance with some embodiments of the present invention. Plot **1405** shows

15 the coding scheme that is being used (values at right vertical axis), while plot **1410** shows the data rate approximately as a rolling average over four time slots (one frame). Initially, CS-4 is used at full duty cycle as the coding scheme combination. A high data rate (approximately 72 kbps) is achieved until the buffer in the mobile station fills, at which time **1415** an acknowledgment is

20 missed. The duration from the start of the data message transmission until the missed acknowledgement is noted (**FIG. 13**, step **1310**); at which time the coding scheme combination is changed to CS-3 at full duty cycle. More acknowledgements are missed, while an average data rate of about 32 kbps is achieved, so the coding scheme combination is changed **1425** to CS-3 at 50%

25 duty cycle and CS-2 at 50% duty cycle, and the average data rate increases to approximately 40 kbps. No acknowledgements are missed after a predetermined time, so a new combination of coding schemes is started **1430** that comprises CS-3 at 75% duty cycle and CS-2 at 25% duty cycle. No acknowledgements are missed using this new combination of coding schemes,

30 and the most recent increment of data rate change was less than a precision limit, so the most recent combination of coding schemes becomes the optimal combination of coding schemes. The data rate for the optimal combination of coding schemes is approximately 51 kbps. This has been determined without the mobile station informing the fixed network of the transfer data rate (which,

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by inference, is greater than approximately 51 kbps and less than approximately 72 kbps). It will be appreciated that for messages of sufficient length, more combinations of coding schemes could be used to establish the optimal coding scheme combination very close to the actual data transfer rate.

5   When the actual transfer data rate has been bracketed by the data rate of the optimal coding scheme combination and a data rate of a previous coding scheme combination, the buffer size is estimated using the faster of the two data rates, which in this example would be 51 kbps.

Referring to **FIG. 15**, a time plot shows data packets of another data

10   message having a long set of data, in accordance with some embodiments of the present invention. The data is being sent to the same mobile station within a short period of time after the initial set of data that was sent, as described with reference to **FIG. 14**. (The short period of time should be less than the duration of the timer set at step **850**.) This set of data can now be transmitted

15   more efficiently by using a combination of coding schemes that has a data rate exceeding a data rate of the optimal combination of coding schemes until the time **1505** at which the estimated buffer depth of the mobile station is calculated to be filled, then using the optimal combination of coding schemes **1510** (or, a slower combination of coding schemes could be used, as

20   appropriate to accommodate other mobile stations) for subsequent transmissions of data of the long set of data.

It will be appreciated by now that an optimal combination of coding schemes and estimated buffer capacity may be determined in a data packet radio communication system without the mobile station informing the fixed

25   network of the transfer data rate, and these parameters may be used to improve the throughput of data messages in the radio communication system.

In the foregoing specification, the invention and its benefits and advantages have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications

30   and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. The benefits, advantages, solutions to problems, and any

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element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims.

As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

A "set" as used herein, means a non-empty set (i.e., for the sets defined herein, comprising at least one member). The term "another", as used herein, is defined as at least a second or more. The terms "including" and/or "having", as used herein, are defined as comprising. The term "coupled", as used herein with reference to electro-optical technology, is defined as connected, although not necessarily directly, and not necessarily mechanically. The term "program", as used herein, is defined as a sequence of instructions designed for execution on a computer system. A "program", or "computer program", may include a subroutine, a function, a procedure, an object method, an object implementation, an executable application, an applet, a servlet, a source code, an object code, a shared library/dynamic load library and/or other sequence of instructions designed for execution on a computer system. It will be further appreciated that a method or function that is typically implemented by the execution of programmed instructions by a processor may be entirely implemented without a processor and programmed instructions; an apparatus comprising a plurality of application specific logic state machines may be used instead to determine an optimal set of coding schemes.

What is claimed is: